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LIFE CYCLE MANAGEMENT

Integration of life cycle assessment in the environmental information system

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Abstract
Background, aim, and scope As the sustainability improvement becomes an essential business task of industry, a number of companies are adopting IT-based environmental information systems (EIS). Life cycle assessment (LCA), a tool to improve environmental friendliness of a product, can also be systemized as a part of the EIS. This paper presents a case of an environmental information system which is integrated with online LCA tool to produce sets of hybrid life cycle inventory and examine its usefulness in the field application of the environmental management.
Main features Samsung SDI Ltd., the producer of display panels, has launched an EIS called Sustainability Management Initiative System (SMIS). The system comprised modules of functions such as environmental management system (EMS), green procurement (GP), customer relation (e-VOC), eco-design, and LCA. The LCA module adopted the hybrid LCA methodology in the sense that it combines process LCA for the site processes and input–output (IO) LCA for upstream processes to produce cradle-to-gate LCA results. LCA results from the module are compared with results of other LCA studies made by the application of different methodologies. The advantages and application of the LCA system are also discussed in light of the electronics industry.
Results and discussion LCA can play a vital role in sustainability management by finding environmental burden of products in their life cycle. It is especially true in the case of the electronics industry, since the electronic products have some critical public concerns in the use and end-of-life phase. SMIS shows a method for hybrid LCA through online data communication with EMS and GP module. The integration of IT-based hybrid LCA in environmental information system was set to begin in January 2006. The advantage of the comparing and regular monitoring of the LCA value is that it improves the system completeness and increases the reliability of LCA. By comparing the hybrid LCA and process LCA in the cradle-to-gate stage, the gap between both methods of the 42-in. standard definition plasma display panel (PDP) ranges from 1% (acidification impact category) to −282% (abiotic resource depletion impact category), with an average gap of 68.63%. The gaps of the impact categories of acidification (AP), eutrophication (EP), and global warming (GWP) are relatively low (less than 10%). In the result of the comparative analysis, the strength of correlation of three impact categories (AP, EP, GWP) shows that it is reliable to use the hybrid LCA when assessing the environmental impacts of the PDP module. Hybrid LCA has its own risk on data accuracy. However, the risk is affordable when it comes to the comparative LCA among different models of similar product line of a company. In the results of 2 years of monitoring of 42-in. Standard definition PDP, the hybrid LCA score has been decreased by 30%. The system also efficiently shortens

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man-days for LCA study per product. This fact can facilitate the eco-design of the products and can give quick response to the customer's inquiry on the product's eco-profile. Even though there is the necessity for improvement of process data currently available, the hybrid LCA provides insight into the assessments of the eco-efficiency of the manufacturing process and the environmental impacts of a product.

Conclusions and recommendations As the environmental concerns of the industries increase, the need for environmental data management also increases. LCA shall be a core part of the environmental information system by which the environmental performances of products can be controlled. Hybrid type of LCA is effective in controlling the usual eco-profile of the products in a company. For an industry, in particular electronics, which imports a broad band of raw material and parts, hybrid LCA is more practicable than the classic LCA. Continuous efforts are needed to align input data and keep conformity, which reduces data uncertainty of the system.

Keywords Eco-design · Enterprise resource planning (ERP) · Environmental information system (EIS) · Green procurement (GP) · Hybrid LCA · Life cycle assessment (LCA) · Plasma display panel (PDP) · Sustainability management

1 Background, aim, and scope

As the people's awareness on the environment increases, industries also face more challenging and diversifying environmental issues than ever. Legal pressures by the environmental regulation not only affect production but also products. Therefore, the objective of environmental control is not only limited to the production process but also urged to expand the product's life cycle. According to the paradigm shift, technologies such as quantification of environmental impact and optimization among different values of different stages on product life cycle are important. Realizing the aforementioned fact, many companies are adopting environmental information systems (EIS) which are based on the life cycle assessment (LCA). The systemized LCA tool reduces the resource and time consumption for gathering data in life cycle inventory (LCI) analysis.

LCA has been developed as a tool to assess the environmental impacts of products, accounting for the emissions and resource uses throughout the life cycles of the product. The role of LCA includes identifying opportunities to improve the environmental performances of products and inform stakeholders to adopt strategic planning, priority setting, and product or process design (ISO 2006a). The usefulness of LCA has been highlighted, as it is emerging as a tool to promote sustainable patterns of production and consumption and to increase the eco-efficiency of products and services (EEA 1998). Although the LCA methodology has been developed and improved since early 1990, some practical difficulties still exist. One of the issues that have most frequently been discussed is the system boundary selection and consequent flow identification to be covered. The system boundary should be modeled in such a manner that inputs and outputs at its boundary are elementary flows (ISO 2006a), which means that the system should include all processes relating substances and parts imported to the product system of study. Considering that the industries are connected to each other by materials flow, developing LCI up to elementary flows for the target product cannot be easily attained. Although insignificant flows can be excluded, as indicated by the international standard documents of ISO 14040s (ISO 2006b), the completeness of LCI is a top concern in many LCA studies (Lindfors et al. 1995). It is due to the complexity of the upstream requirements for the goods and services (Lave et al. 1995).

To overcome this fact, hybrid LCA has been suggested. In the course of its development, a breakthrough was the idea of combining process analysis with input–output (IO) analysis, forming a new tool of analytical framework (Suh et al. 2004). While most LCA studies performed are based on LCI compiled by a conventional process analysis approach, IO LCA uses economic IO tables (IOT) to compile LCI. Since the IOT covers whole industry sectors of a country or a region, IO LCA no longer needs to make cutoff or exclude parts of the product system. However, the IO LCA has its own disadvantages, including the high level of aggregation in industry or commodity classification, oldness of data to catch up new technology, and distortion of physical value converted from monetary unit (Suh et al. 2004). Hybrid LCA is introduced to overcome the disadvantages of both process analysis LCA and the IO LCA by combining those two approaches. Suh and Huppes (2005) classified hybrid LCA into three different categories: tiered hybrid LCA, input/output-based hybrid LCA, and integrated hybrid LCA, based on the way of combining the process analysis LCA and the IO LCA.

Nowadays, many companies have systemized LCA tools to utilize the LCI/LCA results of their products for routine environmental management activities. This fact is highlighted on the electronics industry where they import broad bands of parts and have short product model cycles. Complex products made of many subparts require much time to collect data for the LCA study; moreover, short model change cycle makes the LCA task enormous. Unlike set makers, part and subcomponent makers which export semi-products to set makers have been receiving LCA requests from their customers in various and complicated forms. The resource and time-consuming aspects of data collection in LCI analysis urges industries to introduce

systemization of the LCA. Three different interface methods for the online LCA data gathering method were discussed (Januschkowetz et al. 2000; Moon et al. 2003). The methods differentiated by the degree of integration between the LCA tool and the enterprise resource planning (ERP) system are: interfacing of the external LCA software linked with the ERP system, adapting the complete LCA functionality into the ERP system, and adding the life cycle impact assessment (LCIA) part out of the LCA into the ERP system while connecting the remaining parts for the LCA software with the ERP system.

In the LCA study conducted in part and subcomponent manufacturing, the system boundary is set as a "cradle-to-gate" manner (Andræ Anders et al. 2005). Although the systemized LCA tool utilizes site data (gate to gate data) through the interface with other system, it still needs the LCA data for substances and parts from vendors which are not mostly managed by the company. Collecting relevant LCI data from vendors could be a tremendous job. In this case, the hybrid LCA can be a good answer. This is especially true when the industry uses LCA results for day-to-day application in the industry. Even though the application of the hybrid LCA for some electronic products was conducted (Krishnan et al. 2004; Scharnhorst 2008) and the information-technology-based EIS and LCA systems have recently been studied (Moon et al. 2003; Kobayashi et al. 2002; Frischknecht and Rebitzer 2005), the case of IT-based hybrid LCA is rare in the electronics industry.

With the necessity of the integration of environmental information of a company, this paper presents a case of an environmental information system which is integrated with the online LCA tool to produce sets of hybrid LCI data and examine it with the conventional LCI data to determine whether it is reliable for the intentional application by comparing LCA results between different methods of plasma display panel (PDP) products of a company.

2 Needs for integrated environmental information system

2.1 Reasons for integration of environmental data

The reasons why companies introduce an integrated environmental management system can be described as follows:

- To facilitate sharing environmental information: Environmental management system (EMS) becomes a general practice in reducing the environmental impact of business. EMS is a systematic tool to measure environmental impacts and manage their risks at all levels, from procurement to manufacturing, product development, and marketing. The selections of raw materials of the procurement section, for example, can affect the pollutants emission from a manufacturing facility. The marketing policy has to consider the eco-profile of the product. It means that the environmental data should flow through the functional sections of a company for a successful operation of EMS. If we call it as the vertical integration of environmental data, other dimensions of integration are also necessary to consider a life cycle of a product (Fig. 1). To evaluate the environmental profile of a product, all stages ranging from raw material acquisition to manufacturing, usage, and final disposal are to be considered. It means that the company should gather data from both internal and external of its production site boundary. As the LCA becomes a common practice in industries, LCA data communications between organizations of the same supply chain Eco-Products, 2002) and is expected to increase, for example, environmental declaration of product (EDP) and recent issue on carbon footprint.
- To accelerate sustainability management of the company with efficiency: The integration of environmental

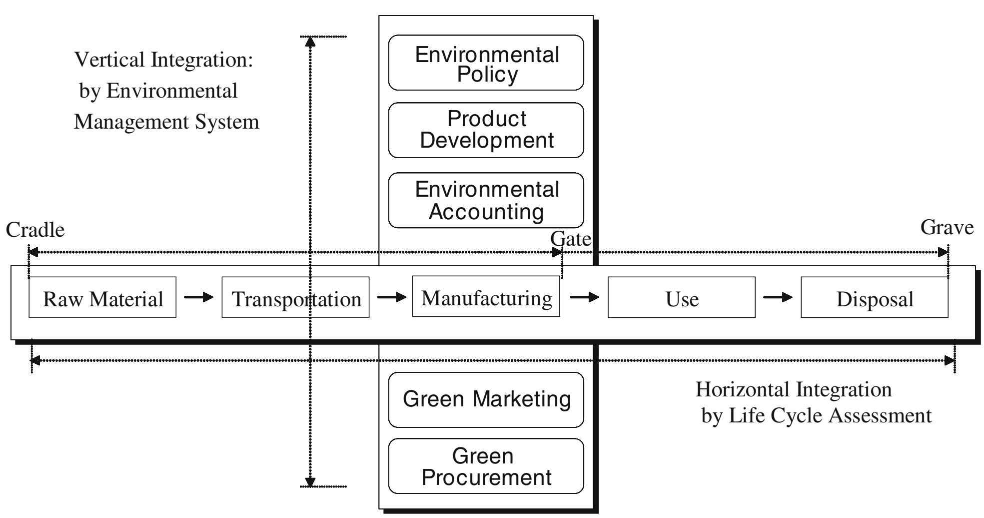

Fig. 1 Vertical and horizontal integration of the environmental information

data and the construction of IT infrastructure can shorten man-days for LCA study per product efficiently. The environmental information system may cut down manual input and improve data quality so that the system gets far more efficient.

- To comply with regulation on product: The necessity of horizontal integration of environmental data is highlighted when it comes to the product-based regulation. In the case of reduction of hazardous substances (RoHS), one of the hottest current issues in the electronics industry, the set maker should keep certain hazardous substances under a required level. To comply with RoHS, the company should know the concentration of those hazardous substances in the parts purchased from outside of the company. Gathering these data needs quite a lot of resources even for ordinary electronics products. When a company has some brand of electronics frequently changing its designs, an integrated computational system is required to manage all the data. Many parts makers in the electronics industry are increasingly facing data enquiries from customer companies.
- To quantify environmental performance: Communicating on environmental performance with stakeholders is becoming a common practice for organizations. The International Standard for the Environmental Performance Evaluation (EPE), ISO 14031, recommends a company to assess a broad range of indicators in the area of its operational and managerial environmental performance as well as the environmental condition. Because all the activities of an organization are related to environmental performances, both directly and indirectly, gathering and calculating data are not a simple job. Considering that the EPE is one of the core parts of EMS, an integrated data system can facilitate the sustainability management of an organization. Many organizations have been publishing an environmental report since the mid-1990s. However, after 2001, it is required to mention not only environmental performance but also economic and social aspects of the organization. To respond to the requirement, some leading companies are now publishing sustainability reports which are usually accompanied by third-party verification. The integrated data management system may improve the completeness and transparency of the report.
- To evaluate indirect environmental performance: Cleaner production is a practice of reducing the environmental impact by improving the production process. Improvement of the process results in less consumption of resources such as energy, water, and other raw materials, along with the reduction of the amount of emission. In the perspective of supply chain, any reduction of resources can achieve a reduction of pollutant emission, an indirect emission, within the supplier's boundaries. The indirect environmental performance is an important concept in an environmental profile of a product since every activity in a life cycle of the product affects the profile. Indirect emission is also important regarding greenhouse gas (GHG) inventory. According to ISO 14064 (ISO 2006c), indirect GHG emission is classified as "energy indirect" and "other indirect" emission. Energy indirect emission is the emission from the generation of imported electricity, heat, or steam consumed by the organization. Other indirect emission is the emission due to a consequence of an organization's activities arising from sources that are controlled by other organizations. Therefore, to implement GHG inventory, an organization should integrate data both internally and externally of its own operational boundary.

2.2 Needs for IT infrastructure

As shown in Fig. 1, the information to be integrated includes almost all of the activities of a company, vertically, and should cover all the environmental impacts, tracked up and down, throughout the life cycle of the product, horizontally. It could be huge. It is more serious in the case of an electronics company which uses many parts to produce broad bands of products. In Samsung SDI, for example, the number of data to be controlled is assumed to reach about ten million in a year. In that sense, if a company is willing to control the environmental profile of products as its usual management, an IT system is necessary. The computerized system could control the huge data as a routine business activity by a just-in-time manner without manual error. The system can also enhance the application of the environmental information among departments of the company to facilitate EMS by sharing the environmental information. Moreover, it makes it possible to keep accuracy of data and transparency of information on the environmental issues.

Currently, many companies have their ERP systems to centralize data relating to the company's business activities and to optimize the use of human and physical resources. An environmental information system can be constructed as a module of ERP. When the system is interfaced to the data warehouse of ERP, it can then import necessary data from other modules of ERP such as procurement, process control, and product sales in an online and real-time manner. For an assembly company, let us say an electronics company, data interface with the procurement module is important since most parts of their products are imported from vendors. The environmental information system can

be constructed to include the functional modules of environmental management, such as environmental accounting (EA), environmental performance evaluation (EPE), green procurement (GP), eco-design, and LCA. Those modules can share data with each other. LCA module, for example, collects data from GP and legacy systems like bill of material (BOM) to produce the LCI/LCA results which are exported to the eco-design module to support the development of a new product and electronic voice of customer (e-VOC) module to support quick response of customer's inquiry on the environmental profile of products.

3 Main features

3.1 System configuration and functions

Samsung SDI Ltd. is the producer of a PDP, liquid crystal display, cathode ray tube, and rechargeable batteries, of which annual sales amounted to US $7.8 billion in 2005. It has 17 global branches, including 12 production sites and two R&D centers. As a display supplier to final set makers, Samsung SDI has been receiving many enquiries on the environmental data of the products from customers who are attempting to incorporate environmental concerns into their product design to reduce environmental impacts and consumers who are interested in choosing products with low environmental impacts.

If the company keeps all the data aligned to prepare those enquiries, the amount of data could amount to almost ten million, 2,400 models, average of 50 parts and 76 data per parts. Having to handle a heavy load of data is one of the important reasons of introducing EIS, as in this case, Sustainability Management Initiative System (SMIS).

Vertical integration of environmental information is another driving force of the system. Samsung SDI launched a company-wide campaign for sustainability management in 2004. As all the functional units of the company were participating in the sustainability management (SM), a core system was needed as a module of ERP for sharing the environmental information within a company. The system was launched in January 2006 and covers all sites and offices of the company throughout the world.

SMIS comprised four functional modules (GP/ED, EMS, LCA, and EA), two SM modules, and one integrated database (Fig. 2). Legacy systems connected to the SMIS include GP and e-VOC modules and other ERP modules. All the modules exchange relevant data through the integrated database.

The functions of each module are as follows:

- EMS module: It controls operational reports on environment facilities, toxic chemical data, pollutants emission data, and so on. All the data are managed in real time and are used as basic data for LCA and eco-design (ED). EMS module cuts down manual input and improves data quality so that the EMS gets far better efficiency.
- EA module: The module supports cost–benefit analysis of environmental investment and operation. It shares the data with ERP, investment management system, and the EMS.
- GP/ED module: GP enables cooperation with S-partners, the environmentally eligible suppliers verified by Samsung Electronics Group, and assesses the environmental performance of their parts. Meanwhile, ED supports eco-design. Aligned with BOM of ERP, the module enables responding to customers' request on product environmental profile immediately.

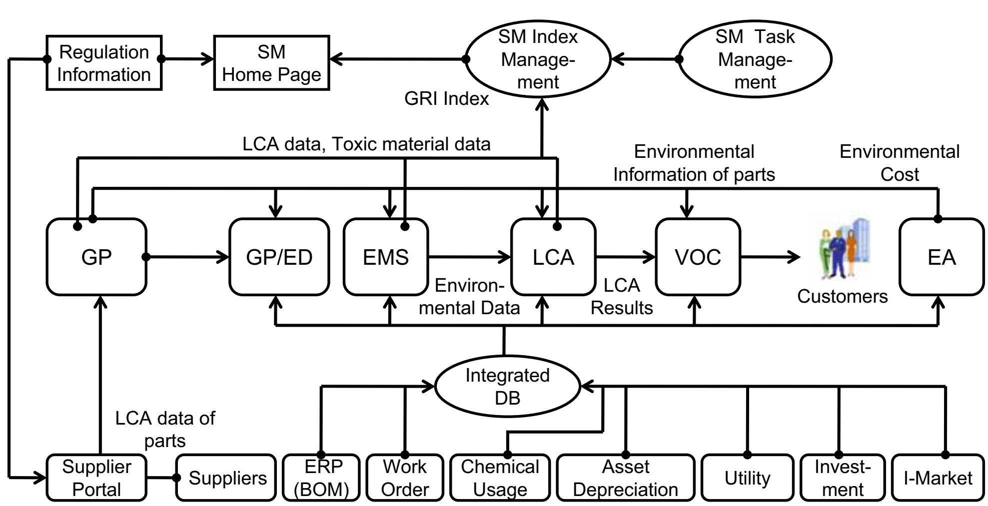

Fig. 2 Overview of data flows and functions of each modules in SMIS

- LCA module: LCA quantifies material consumption and generation, energy use, and emission throughout the life cycle of a product and analyzes eco-friendliness of the product. It is linked to integrate the utility system to allocate utility use by processes and collect basic LCA data of the parts from the suppliers. It automatically generates LCA scores for all products developed in a company.
- Sustainability management task (SMT) management module: Samsung SDI deploys many tasks to improve the sustainability of the company. The tasks, which are developed according to the company's SM strategies, are classified into the environmental and social areas. SMT is a monitoring system for the evaluation of SM's task progress and status. All SM tasks have department/strategy codes to weigh up each department's efforts on SM.
- Sustainability management index (SMI) management module: SMI manages economic, environmental, and social indices to evaluate the sustainability of the company. Employees can have access to the indices selected according to the global standard. SMI provides a holistic view on SM progress and users can analyze in detail statuses and situations by division and plant.

3.2 Hybrid LCA application

The LCA module of SMIS is deployed to execute hybrid LCA based on the combination of IO data for upstream flow and process LCA data for company's site boundary (Fig. 3). The biggest practical obstacle in applying IO data to LCI is the lack of applicable sectoral environmental data in most countries. Although there are some emission inventory databases available, differences in the level of detail, base year, and industry classification make it difficult to construct well-balanced sectoral environmental data in most countries. In the case of Korea, IOT to LCI is being performed in the research stage. Environmental input–output table for raw material is prepared in GP module based on a monetary unit from EIO database referenced by Missing Inventory Estimation Tool (MIET) 2.0 software, which had been developed to supply data to tiered hybrid analysis. The 2.0 version of the tool prepared database based on the 1996 US IO table and environmental statistics (Suh 2001; Suh and Huppes 2002). From the MIET 2.0 database, 34 applicable industries are selected as the representing materials and parts imported from vendors for the product manufacturing. Samsung SDI is managing it by classifying all the materials and parts into three layered groups. In the most detailed classification, 301 parts are listed until January 2006. Those 301 parts are connected to one of the 34 applicable industries of IO DB in the GP module which is interfaced with the parts price master table to find the monthly moving price. The prices are actual ones determined by contracts with vendors. Transportation expenses to Samsung SDI are also included in all the prices.

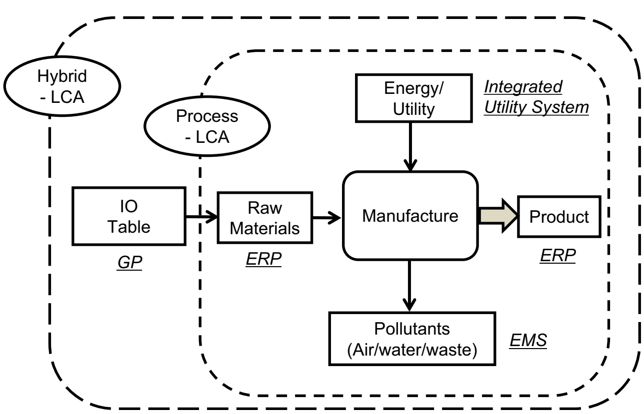

Fig. 3 System boundary of hybrid LCA and process LCA

The process LCA data are prepared by interfacing with ERP and legacy systems such as Integrated Utility System and EMS. For a target product, the LCA tool collects input data of raw materials and parts from the BOM of ERP, energy usage data from Integrated Utility System, the energy management system of the company, and pollutants emission data from EMS. The input of product weight (kg) is done manually every month. However, the product weight will be automatically interfaced with ERP linked in the future. An LCA expert in each production site inputs allocation factors for air emissions, water effluents, and wastes by product and process on the basic information of the LCA module. All those data are classified by process level and are allocated according to the LCA methodology (Samsung SDI 2007). Since the LCA tool collects all data automatically through interface with other systems, the practitioner can get the LCA results for selected products for a selected time period without manual input for data gathering. Currently, Samsung SDI evaluates LCA results monthly for its products as a routine process. In addition, the LCA results are exported to GP and VOC modules to support product development and to reply to customer's inquiries on the eco-profile of the products.

4 Reliability of the hybrid LCA results

To evaluate the reliability of the hybrid LCA results by the systemized tool, a full LCA case study on PDP TV has been done for the comparison. The process LCA for 42-in. PDP TV mounting Samsung SDI PDP module was executed by Samsung Electronics Co. Ltd. to obtain the certification of the Korean Environmental Declaration of

Table 1 Execution conditions of hybrid LCA and process LCA for the reliability of LCA results

Method	Reference flow	System boundary and data collection				Time span
		Upstream	PDP module manufacturing	PDP TV manufacture	use and disposal	
Hybrid LCA	42-in. SD PDP module	IO data	Site data	–	–	After 2006, monthly base
Process LCA (type III)	42-in. SD PDP TV	Site data	Site data	Site data	Site data	On 2002

Products, the type III environmental labeling, on 2002 (Korea Eco-Products 2002). Since Samsung SDI produces PDP modules of the TV, even though the system boundary and time span are different, the results of the two cases can be compared. The two studies are summarized in Table 1. Hybrid LCA for 42-in. Standard definition (SD) PDP module was executed monthly by Samsung SDI Ltd. since January 2006. The system boundary is defined as cradle-to-gate manner. On the other hand, the process LCA study by Samsung Electronics was done for the full life cycle stages from cradle to grave based on the data of 2002. To compare these two cases, two assumptions were made: The eco-profile of PDP panel is 30% that of a PDP TV (Displaysearch 2006), and the difference of time span can be calibrated proportionally by the ratio of cost difference.

Many researchers have used a number of techniques to compare and evaluate the various methods of LCA. These have included error analysis (various types, including truncation error analysis), gap analysis, and comparative analysis (Lenzen 2001). Error analysis is used to assess the accuracy associated with the use of IO data for modeling system inputs and evaluating initial data inputs. Other methods have been developed to overcome the limitation of error analysis by focusing on the outputs of the LCA methods. Gap analysis and comparative analysis are used to assess the difference between the process analysis results and the hybrid analysis results as an evaluation of the completeness and reliability of each method (Crawford 2008). The last two methods are used in this study.

The gap analysis has been used to assess the comparison of different LCA methods as a measure of completeness. In the result of both LCA methods, the impact categories in PDP manufacturing stage include global warming (GWP), acidification (AP), abiotic resource depletion (ADP), ozone layer depletion (ODP), eutrophication (EP), and photochemical oxidant creation (POCP). The six impact categories in PDP manufacturing stage are in a range of 3.26×10^2–3.41×10^{-4} units/PDP module by the hybrid LCA and in a range of 3.55×10^2–5.33×10^{-6} units/PDP module by the LCA process (Table 2). Global warming, acidification, and eutrophication impacts in the PDP manufacturing stage by both methods have a similar range of impact scores. Abiotic resource depletion and photochemical oxidant creation impacts in the PDP manufacturing stage by the hybrid LCA have relatively lower impact scores than those obtained by the process LCA. Ozone layer depletion impacts in

Table 2 Comparison of hybrid LCA value and process LCA value

Impact categories (units/PDP module)	Hybrid LCA value[a]	Process LCA value[b]				Gap=$(a-b)/a\times 100$ (%)
	Manufacturing stage (a)	Manufacturing stage (b)	Use stage (c)	End of life stage (d)	Total ($e = b + c + d$)	
Abiotic resource depletion (kg Sb-eq)	7.97×10^{-1}	3.04	1.52	1.19×10^{-3}	4.56	−282
Global warming (kg CO_2-eq)	3.26×10^2	3.55×10^2	2.41×10^2	2.16×10^{-1}	5.96×10^2	−9
Ozone layer depletion (kg CFC11-eq)	3.41×10^{-4}	5.33×10^{-6}	9.00×10^{-8}	1.65×10^{-8}	5.45×10^{-6}	98
Acidification (kg SO_2-eq)	1.92	1.90	1.18	1.52×10^{-3}	3.04	1
Eutrophication (kg PO_4^{3-})	1.23×10^{-1}	1.17×10^{-1}	7.48×10^{-2}	1.78×10^{-4}	1.90×10^{-2}	5
Photochemical Oxidant Creation (kg C_2H_4-eq)	1.44×10^{-1}	4.69×10^{-1}	2.54×10^{-1}	2.41×10^{-4}	7.23×10^{-1}	−226

[a] Hybrid LCA value: [used amount of each raw and subsidiary material] × [unit cost/one module of PDP] × [environmental effects/unit cost; statistical value for the industry from MIET 2.0 software]

[b] Process LCA value converted by the price reduction ratio during 2002–2006 and the fraction of PDP module in PDP TV. PDP price in 2002 is $1,467/PDP module; PDP price in 2006 is $620/PDP module. The fraction of PDP module in PDP TV estimated as about 30% of PDP TV

the PDP manufacturing stage obtained by the hybrid LCA have greater relative impact scores than those by the process LCA. The ranges of impact scores are 3.41×10^{-4}kg CFC11-eq/PDP module and 5.33×10^{-6}kg CFC11-eq/PDP module by the hybrid LCA and the process LCA, respectively.

By comparing the hybrid LCA and the process LCA in the manufacturing life cycle stage, the gap between both methods of the 42-in. SD PDP panel ranges from 1% (acidification impact category) to −282% (abiotic resource depletion impact category), with an average gap of 68.63%. The gaps of the impact categories of abiotic resource depletion, photochemical oxidant creation, and ozone layer depletion are greater than the gaps of the impact categories of acidification, eutrophication, and global warming. Because of the limitation of assumptions and possible hidden error in each case, the gap could not be explained clearly.

The comparative analysis has been used to compare those two LCA results as a measure of reliability evaluation. In this case study, comparative analysis was made to evaluate the impact of manufacturing life cycle stage of PDP module (Fig. 4) experimentally by applying the process LCA and the hybrid LCA. A logarithmic scale was used to avoid smaller values being lost for the sake of visual comparison. The comparative analysis between the hybrid LCA results and the process LCA results show that the values provided by the hybrid LCA results do not give an accurate indication or representation of the equivalent process LCA results on each impact category or whole product level. The correlation between the log(hybrid LCA) and log(process LCA) for manufacturing life cycle stage impacts of PDP module shows that the strength of trends on three impact categories in both methods is significantly strong to use the hybrid

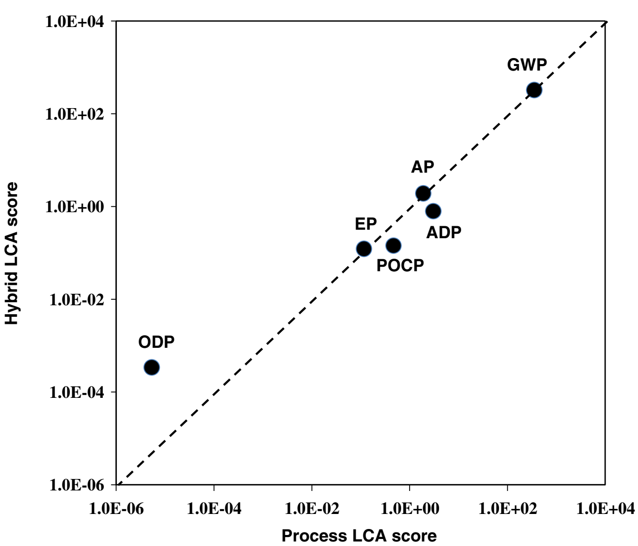

Fig. 4 Correlation between log (hybrid LCA) and log (process LCA) regression for manufacturing life cycle stage impacts of the PDP

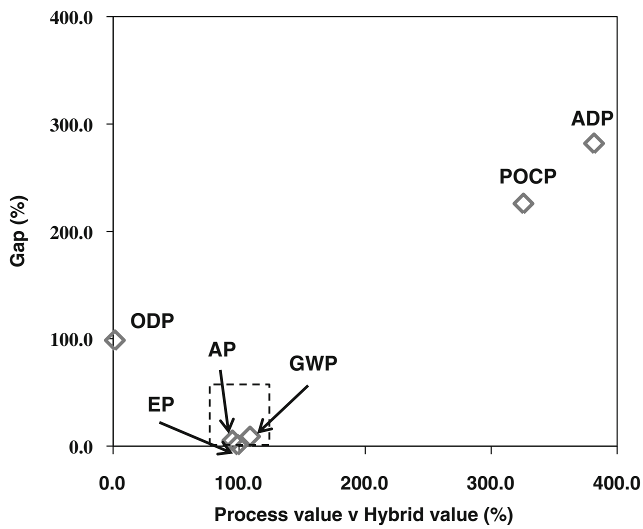

Fig. 5 Relationship of gap and process versus hybrid LCA value comparisons on impact categories

LCA when assessing the environmental impacts of products. This comparison shows a strong relationship for three impact categories (AP, EP, and GWP) and very little correlation for the other three impact categories (ADP, POCP, and ODP).

The relationship between the values obtained from the gap analysis and the comparative analysis can be used to determine the completeness and reliability of each method. This relationship is shown in Fig. 5. The gap values, shown on the "*y*-axis", represent the percent gap between the process-based and the hybrid LCA results for the impact categories. The "*x*-axis" represents the comparisons between equivalent process and the hybrid LCA values for the impact categories. These values are converted to a percentage of correlation between the two values. Ideally, for the hybrid LCA data to be shown to provide an accurate representation of equivalent process LCA data values and to achieve a reliable and comprehensive LCA, there should be a relatively low gap (closer to 0% on the *y*-axis) and a close correlation between process and the hybrid LCA values (close to 100%).

As the evaluation between the gap and comparison between the process and the hybrid LCA results has shown that three impact categories (EP, AP, GWP) have a low gap and strong correlation, it can be assumed that the hybrid LCA results provide an accurate representation of the equivalent process LCA results for PDP module. However, three impact categories (ODP, POCP, ADP) have a high gap and low correlation, and it can be assumed that the quantity of currently available process LCA data are not sufficient to confirm the reliability of the hybrid LCA results. The limitations in this study have shown that there is a lack of process data currently available and further improvements in the quantity of this data are needed to increase the reliability of LCA. Subsequent comparison of LCA methods may be

necessary in light of expected progressive improvements in hybrid LCA result availability. Therefore, efforts must be made to collect more process LCA results for further analysis.

Figure 6 shows the LCA score monitored by the LCA module of SMIS and price trend of a 42-in. SD PDP module from January 2006 to December 2007. During that period, the LCA score based on the Life cycle impact assessment (LCIA) methodology has been decreased by 30%, while price dropped by 50%. The fact implies that the hybrid LCA results by the LCA module of SMIS reflect some portion of the product price, for example 60% in this data sample. The factor contributing to the improvement might be the reduction of primary and ancillary inputs by the improvement of efficiency in the manufacturing process. In general terms, price is the result of an exchange or transaction that takes place between two parties and refers to what must be given up by one party (i.e., buyer) in order to obtain something offered by another party (i.e., seller). The other part is the volume of the goods traded per unit time, called the rate of purchase or sale. Price in economics and business is the result of an exchange and, from that trade, we assign a numerical monetary value to a good, service, or asset. Price drop of products will be caused by factors, partly due to the contributions of price change, and somewhat due to increasing efficiency in resource use. The improvement of resource consumption and process in manufacturing stage might have been reflected in the price drop of products. Therefore, periodic monitoring of the hybrid LCA provides an insight into the assessments of the eco-efficiency of manufacturing and the environmental impacts of a product.

5 Conclusions

As the environmental issues are being essential in industries, the need for environmental data management is also increasing. LCA shall be a core part of the environmental information system by which the environmental performances of products are controlled. Hybrid type of LCA is effective for the purpose of usual eco-profile control of products in a company. In an industry, in particular electronics, which imports a broad band of raw material and parts, hybrid LCA is more practicable than the classic LCA. SMIS, the environmental information system of Samsung SDI, provides a method for the application of IT-based hybrid LCA through online data communication with environmental management system and green procurement module. Before SMIS was adopted, data communications with suppliers was used to be done manually. In that case, when Samsung SDI received a data enquiry from a customer, they had to reply to it manually. For this purpose, the company had to carry out LCA studies or gather instant data from suppliers, which was a tedious and time-consuming task. After launching SMIS, VOCs are uploaded to the system and relevant data are prepared by computational process by the system itself. The system accelerates the sustainability management of the company with reduced human resources input. The IT-based LCA can perform as an essential tool in the sustainability management by finding environmental burden of products, especially in the electronics industry, since the electronic products have some critical public concerns in the use and end-of-life phase. The environmental information system provides efficient eco-profiles of products to support the eco-product development strategies of a company.

This paper has assessed the reliability of the hybrid LCA results produced by SMIS by comparing it with the process LCA results of a PDP module. Even in the limited source of the process LCA data, the experimental results of the comparative analysis show that the hybrid LCA is positively related to the process LCA in some impact categories (AP, EP, and GWP), while some gaps are observed in other impact categories (ADP, POCP, and ODP). Even in the case of the observed gaps, the hybrid LCA results can be used to monitor the trends of the eco-profile of the products or to

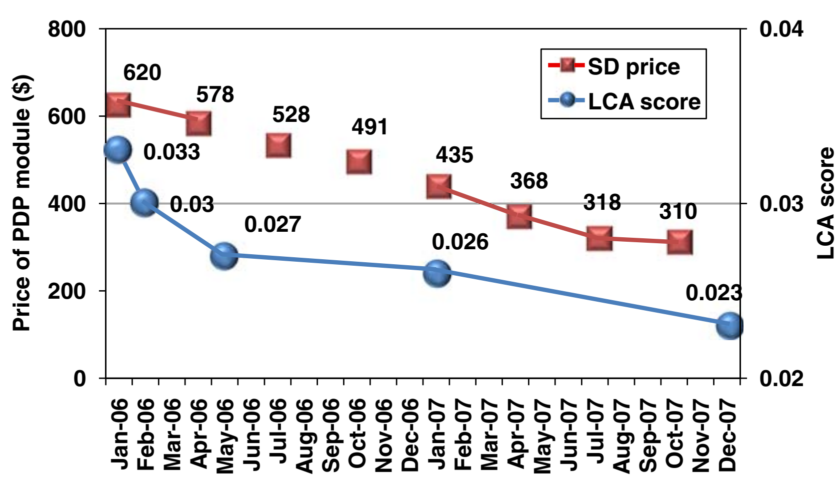

Fig. 6 Monitoring LCA score for the 42-in. SD PDP module and price trends for HD and SD in 42-in. PDP modules

compare the LCA scores between different models of similar product lines of a company.

6 Recommendations

Systemization of the environmental information management, including LCA modules, needs some capital investment. Moreover, it easily fails to keep reliability of functions. Careful approach is desirable on both planning and programming stages. From the experience of Samsung SDI case, key success factors can be suggested as follows:

- Internalize sustainability management of the organization: SMIS is a supporting tool for sustainability management. Therefore, the value of the system is not much if the company does not fully internalize the policy of sustainability management.
- Standardize processes among plants: Manufacturing sites, throughout the world, of an international company should use standardized processes and documents to share information and to integrate activities of all levels to the company-wise sustainability management.
- Replenish necessary hardware: Many data should be collected in the field. Prerequisite measuring equipments should be installed and replenished properly.
- Keep user-friendliness: The system must be easy to use. Any inconvenience of the system becomes a big barrier for the proposed application of the system. Minimizing manual input is also important in that sense.

In the operation stage, data correction may be necessary to improve system accuracy. It is relatively easy to find errors in separate data, whereas hidden errors are not discovered in the case of integrated data. LCA module often requires quite a long time to correct data for getting reliable results. To reduce data uncertainty of the system, continuous monitoring procedure is required to align input data that could keep conformity.

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